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Torsional, tensile and structural properties of acrylonitrile–butadiene–styrene clay nanocomposites

Priyanka Singh, Anup K. Ghosh *

Centre for Polymer Science and Engineering, Indian Institute of Technology Delhi, New Delhi, India

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ABSTRACT

Torsional and tensile behaviour of acrylonitrile–butadiene–styrene (ABS)-clay nano-composites have been investigated and correlated with morphological and rheological characterisations. Nano-composites of ABS are prepared by melt compounding with different loading levels of nanoclay (Cloisite 30B) in a twin screw extruder and have been characterised in terms of torsional, axial and impact behaviour for their application in external orthotic devices. Tensile stress strain curve of nanocomposites are investigated to quantify resilience, toughness and ductility. Torque values of the nanocomposites are observed under torsion (10°–90°) and compared with that of neat ABS. Performance of ABS under torsional load improved by addition of nanoclay. Both modulus of elasticity and rigidity are found to improve in presence of nanoclay. State of dispersion in nano-composites is investigated using conventional methods such as transmission electron microscopy (TEM), X-ray diffraction (XRD), as well as by parallel plate rheometry. Addition of clay exhibits shear thinning effect and results in increase in storage modulus as well as complex viscosity of the nanocomposites. Zero shear viscosity rises tenfold with 1–2% addition of nanoclay, indicating the formation of structural network. It is found that state of dispersion of nanoclay governs the torsional and mechanical properties in ABS-clay nanocomposites.

1. Introduction

Acrylonitrile–butadiene–styrene (ABS) and their nanocomposites need extensive investigation for development of products which include structural components in automotives, enclosures of electrical and electronic parts, home appliances as well as orthotic devices in order to prove the durability and load carrying capacity. Deformation in such parts can be produced by the forces caused by stretching, compressing, twisting and bending. Among these, twisting or torsion is an important force which can produce stresses in application such as hinge joint for orthotic leg. Conventionally torsional behaviour of the structural parts made out of metals and ceramics are investigated [1–3]. But in current research scenario there is still scanty information available for response of polymeric material under torsional deformation. Thus, it is essential to establish torsional response comprehensively to establish performance properties of polymer and their nanocomposites. Torsional measurement is not as universal as tensile and flexural measurement. Torsion is introduced into a bar when it is subjected to a twisting moment and the angle of twist (φ) is calculated using the following equation [4]:

$$\varphi = \frac{TL}{JG} \quad (1)$$

where T is torque, L is gauge length, J is polar moment of inertia and G is torsional rigidity. Polymer is limited for engineering applications due to low modulus of resin, poor thermal resistance and toughness–stiffness balance. Application profile of ABS can be broadened by reinforcing it with nanoclay as it is known to enhance the property of matrix at very low filler loading and thus, broadens the window of properties [5,6]. Nanoclay is mainly layered silicates, having sheet like platelets of about 1 nm thickness and 30 to several microns in length and width. These platelets have very high tensile modulus (170 GPa) relative to that of polymers (>1 GPa) [7] and these are further modified before being added to organophilic polymer matrices [8].

Additionally, dispersion states in the nano-composites lead to different responses for the applied stresses and need to be evaluated. To establish the structure, TEM is a popular method to understand the state of dispersion of platelets in nano-composites but the size of the sample used may not represent the total volume, and the sample preparation for TEM requires special expertise which makes the whole method costly and time consuming [9]. Alternatively, rheology has evolved as a method to characterise the clay dispersions in polymer nano-composites as rheological response of nanocomposites depends on the factors such as filler size, aspect ratio and orientation, filler loading and interaction between polymer and filler [10]. Wagener et al. have discussed the approach to quantify shear thinning behaviour so as to compare exfoliation and nanoscale dispersion in nanocomposites [9].

* Corresponding author. Tel.: +91 11 26591424.
E-mail address: akghosh@polymers.iitd.ac.in (A.K. Ghosh).

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Polymer clay nano-composites have gained interest and popularity as a tool to develop new materials. ABS clay nanocomposites have also been studied by several researchers. ABS clay nanocomposites are generally prepared by processes such as melt-mixing, emulsion and in-situ polymerisation by different researchers [8,11–18]. The preparation of ABS clay nano composites by melt blending have been reported by Wang et al. [19]. In another study three different types of clay i.e. Cloisite 30B, Cloisite 25A and Cloisite 10A are used to prepare ABS clay nanocomposites by solution blending. Cloisite 30B was found thermodynamically more favourable when compared with Cloisite 20A and Cloisite 15A [13,20]. Most of the reports on ABS-clay nanocomposites are focused on thermal stability and flame retardancy [8,14–16,20].

Present work thus, aims to critically analyse the effect of clay on the properties of ABS when it is subjected to torsional, axial, bending and dynamic load. Rheological evaluation has been used as a tool to establish the structure and correlate with TEM and XRD observation. In addition, the effect of clay on the mechanical behaviour and thermal stability of ABS has also been studied.

2. Experimental details

2.1. Materials

Acrylonitrile–butadiene–styrene (ABS) resin containing styrene 60–54%, Butadiene 17–21%, Acrylonitrile 23–25% by weight was procured from Bhansali Engineering Polymers Ltd., India with the trade name Abstron and grade HI40B. Organically modified clay (Na^+-montmorillonite) was chosen for the study and supplied by Southern Clay Products, USA under the trade name Cloisite 30B.

2.2. Preparation of ABS clay nano-composites

ABS-clay nanocomposites were prepared by melt mixing using THERMOSCIENTIFIC (Prism Eurolab 16) twin screw extruder (L/D of 40, barrel diameter of 16 mm, maximum speed of 1000 rpm and maximum torque of 12 Nm). All materials were pre-dried for 4 h at 75 °C under vacuum. The nanocomposites were prepared maintaining the temperature profile of 200–230 °C and at the screw speed of 200 rpm, generating 60–70% torque. The continuous strands from the extruder were pelletized and vacuum dried before injection moulding. L&T DEMAG injection moulding machine (Model: PFY40-LNC4P) was used to prepare test specimens as per ASTM standards for different tests at 200–230 °C. Four compositions were prepared with different clay loading as given in Table 1.

2.3. Characterisation of ABS clay nano-composites

2.3.1. Rheological properties

The melt rheological measurement was done using Bohlin C-VOR rotational rheometer (Malvern Instruments Limited, UK) with the parallel plate geometry. Samples (disc shape) were prepared by compression moulding of dimension 25 mm in diameter and 1 mm in thickness. Samples were initially tested using an amplitude sweep to find out the linear viscoelastic region (LVR). The frequency sweeps between 0.1 and 100 Hz at 0.1 strain unit were carried at 170 °C.

2.3.2. Torsional properties

Torsional testing was carried out using MCR302 DMTA equipment from ANTONPAAR. The DMTA system consisted of a rheometer combined with the convection temperature devices CTD 450 and solid rectangular fixtures. Schematic of the torsional fixtures is presented in Fig. 1. One of the clamps generates torsional movement between 10° and 100°. All the experiments were carried out at 70 °C using injection moulded sample having dimension of 14 mm in length, 9 mm in width and 1.5 mm in thickness. Torque and rigidity modulus were compared for ABS and its nanocomposites as a function of torsional deflection.

2.3.3. Mechanical testing

Samples were subjected to load in tensile and flexural mode using ZWICK Z010. ASTM: D638 was followed to perform tensile test at room temperature at a speed of 50 mm/min. Flexural test was done as per ASTM: D790 method at a speed of 13.5 mm/min. Notched izod impact strength was measured as per ASTM: D256 on a Ceast impact testing machine.

2.3.4. Thermal analysis

ABS clay nano-composites were investigated by thermo gravimetric analysis (TGA), performed with a PERKIN ELMER Pyris 6 (TGA) instrument under nitrogen atmosphere at the rate of 20 °C/min, from 25 to 750 °C. Differential scanning calorimetry (DSC) was performed using DSC 7 instrument (Perkin Elmer) at a scan rate of 10 °C/min to determine the effect of Cloisite 30B on glass transition temperature.

2.3.5. Morphological characterisation

The state of dispersion of clay platelets in the composites was studied by means of transmission electron microscopy (TEM). Freshly cut glass knives with cutting edge of 45° were used to prepare the cryo-sections of 50 nm thickness by using a Leica Ultracut UCT microtome. JEOL-2100 electron microscope (Tokyo, Japan) having LaB6 filament and operating at an accelerating voltage of 200 kV was used. Evaluation of dispersibility of clay in ABS resin matrix was investigated using XRD technique and basal spacing of clay layers was obtained using Bragg's rule. X-ray diffraction experiments were performed at room temperature on X-ray diffractometer (PW 3040/60 X'PERT PRO PANALYTICAL, Netherland), (40 kV, 30 mA) with Cu (λ = 1.54 Å)

Table 1
Rheological and morphological properties of ABS-clay nanocomposites.

Sample designation	ABS (wt%)	Nanoclay (wt%)	Shear thinning component (0.1–1 Hz)	Zero shear viscosity (Pa s)	2θ Value (°)	d Spacing (Å)	Number average aspect ratio $(l/t)_n$
Cloisite 30B	–	–	–	–	4.831	18.29	–
ABS	100	0	0.45	4.98E+05	–	–	–
ABS01NC	99	1	0.46	9.24E+04	2.491	35.41	38.98
ABS02NC	98	2	0.22	3.30E+06	2.49	35.47	46.21
ABS04NC	96	4	0.26	1.67E+06	2.49 5.237	35.47 16.86	34.24
ABS06NC	94	6	0.35	2.36E+06	2.49 5.5	35.51 16.05	28.69